

ENGINE TITANIUM CONSORTIUM

SUMMARY OF ACCOMPLISHMENTS: GRANT NUMBER 93-G-029

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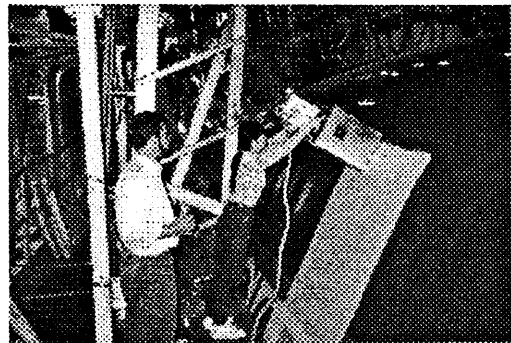
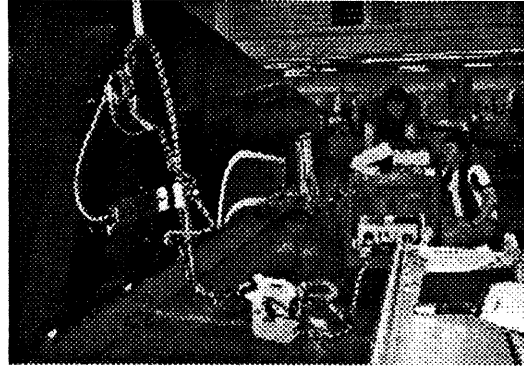
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Major Research Accomplishments:

- CASR research has generated over 45 field tests, 5 licensing agreements, and 3 patents.
- A fieldable prototype of ultrasonic dripless bubbler adapted to commercial scanner for the detection of corrosion and disbonds in fuselage structure. Patent awarded and commercialization agreement in place with Sierra Matrix. Winner of 1996 R&D 100 Award. Featured on CNN's *Science Watch*, the dripless bubbler also has the attention of the rail, naval, space, petroleum, and medical communities. United Airlines and CASR engineers are shown here using the device in inspection of a 757 rudder in April 1997.
- Developed a thermal wave imaging system for large area inspection of fuselage structure. Commercially available and in use at Boeing and Lockheed Martin. Technology transfer initiatives that include the FAA Airworthiness Assurance NDI Validation Center at Sandia National Labs are under way partnered with Boeing, Northwest Airlines, and TWI Inc.



Developed an inspection simulator, a computer software package, that can be used in the development of optimized inspection procedures and training of personnel in a more cost-effective and straightforward manner than existing approaches. Beta site tests at Boeing, Douglas, Pratt & Whitney, and United Airlines are under way.

FUTURE ACTIVITIES

The efforts of the ETC Phase I program were initiated with FAA Grant no. 93-G-029 and continue on FAA Grant No. 94-G-048. The ETC continues to focus on the deployment of technology with major efforts accomplished in cooperation with the titanium producers, the airlines, and the life management community. Cooperative efforts are underway with the Turbine Rotor Materials Design program, a separately funded FAA Grant. A Phase II program is expected to begin in 1998 and will include efforts in production inspection of large diameter titanium billet, nickel billet, titanium forgings; inservice inspection tools for both surface and subsurface inspection of critical rotating engine components; and test and validation tools for use in determination of probability of detection for the tools developed in the program. A companion program is also in preparation to develop and implement improvements in fluorescent penetrant inspection tools and processes. Efforts are coordinated with the FAA New England Engine and Propeller Directorate.

to the edge of a component, a critical area of the engine structure where stresses are higher and cracks initiate.

New tools are being implemented that improve the inspection capability of the aviation industry. Quantifiable results have been demonstrated and the FAA program has delivered technology which improves safety.

IMPACTS TO INDUSTRY COMPETITIVENESS AND INTERNATIONAL IMPLICATIONS

When safety is the prime concern, the solution of technology base issues should take precedence over industrial competitiveness and be made available for implementation by all potential users. To be effective in developing and implementing solutions requires that industrial competitive issues be put aside and members work as a team. The ETC has allowed the three major US engine manufacturers which compete with one another in other arenas to come together to develop new tools to improve safety.

Implementation of the technology is left to the individual companies for consideration in their overall engineering and management strategy. Access to the technology results is provided not only to ETC members but to the aviation community at large including international corporations. Results have been shared with the international engine community including Rolls Royce/Allison, SNECMA, and the Russian Central Institute for Aviation Motors. International companies have also been included in the interactions with billet producers. These interactions ensure that the public funds used to generate safety-related solutions have their greatest impact.

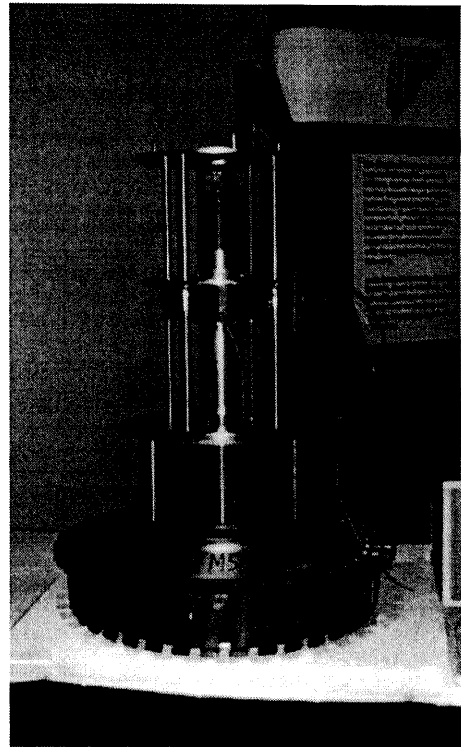
INNOVATIVE APPROACH OF THE ETC

The ETC was established in 1993 to develop and implement inspection improvements recommended by the FAA Titanium Rotating Components Review Team Report (TRCRT). The FAA Review Team was established after the Sioux City crash of 1989 to evaluate the entire titanium lifecycle, from ore to inservice engines, and recommend areas for improvement. Recommendations were made in the areas of inspection, manufacturing, and life management and various research efforts are in place in response to those recommendations. The ETC focus is on cost-effective improvements to the inspection process. Because the implications of such improvements impact the safety of the flying public, the FAA chose to establish a cooperative program that brings together the leading US engine manufacturers with the leading NDE research university. By establishing such a team, the results of the research remain in the public domain.

A major thrust of the ETC program is to improve the sensitivity of inspection through improvements in existing technologies or development of new approaches. The Multizone inspection system has demonstrated a fourfold improvement over existing conventional inspection. Use of zoned ultrasonic inspection, either in billet or forging inspection, reduces the likelihood of hard alpha defects remaining in field hardware and therefore reduces the potential for future catastrophic events. Once in the field, improved scanning and signal processing tools for eddy current inspection are being implemented for detection of service induced defects. These field-ready tools will allow the airlines to perform enhanced inspection of older engine models as well as monitor newer designs. The comprehensive approach taken by the ETC ensures that tools are being developed and implemented to meet the lifecycle inspection needs for titanium.

SUCCESSFUL DEMONSTRATION OF EDDY CURRENT TOOLS TO AIRLINE INDUSTRY

Technology innovations such as computer data acquisition, signal processing and controlled scanning are being implemented in production and defense applications. However, the cost of such innovations has been prohibitive for implementation in field environments. The ETC has focused its efforts on cost-effective and implementable tools for the airline industry. Recently, a portable scanner was demonstrated to the Air Transport Association (ATA) Nondestructive Testing Forum. The ATA NDT Forum is attended by approximately 300 of the air transport industry inspection community, including the inspection management for all the major US carriers. In September 1995, the ETC demonstrated the portable scanner, reaching not only the major US carriers, but representatives from the commuter industry and the third party maintenance community. A bore inspection was demonstrated on a GE CFM-56 titanium disk. The bore or inner diameter is sometimes subject to cracking and represents a likely use of the portable scanner. The industry representatives present were pleased with the progress of the ETC program and several airlines, including Northwest and United, will be serving as beta test sites over the next several months.



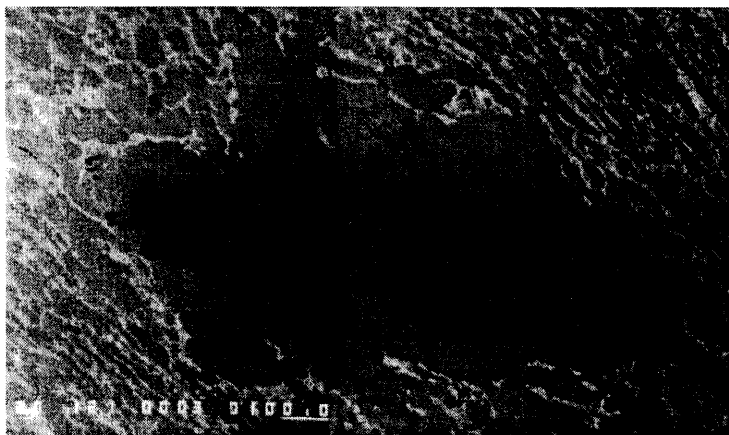
SAFETY IMPROVEMENTS

ETC tools have demonstrated their ability to detect flaws that were undetected with conventional technology as evidenced by the 1/4" find described previously. A comparison of zoned inspection to conventional inspection is currently underway using a contaminated heat of titanium. A heat, or single melt of titanium, weighing 6300 pounds was forged to 6" diameter billets. The preliminary results indicate 59 indications with the ETC Multizone system compared to only 31 indications for conventional inspection. A similar trial is planned for the phased array technology. From the Multizone results, an improvement in detectability has been demonstrated for zoned inspection. Implementation by the industry has also begun with four systems recently installed for use by billet producers, thereby enhancing the safety of today's and tomorrow's engines.

To ensure safety of inservice engines, ETC eddy current technology is also being implemented. New eddy current probes being designed by ETC personnel will be used in upcoming field inspection of PW engines. The portable scanner will also begin more rigorous field tests with several airlines. A 70% improvement is expected in the flaw size that can be detected when comparing the portable scanner results to hand held scans typically used in existing approaches. ETC technology will also allow inspection 75% closer

SUCCESSFUL DETECTION OF HARD ALPHA DEFECT IN TITANIUM BILLET

The Multizone ultrasonic inspection system for billet was developed by General Electric Aircraft Engines (GEAE) in response to FAA recommendations, and is currently demonstrating a fourfold improvement in sensitivity for detection of internal defects. Further refinement of the technique continues under the FAA-sponsored Engine Titanium Consortium. Since early 1995, GEAE required that all rotor-grade titanium receive Multizone inspection. Earlier this summer, a heat of titanium received conventional ultrasonic inspection and was shipped for Multizone inspection and intended eventual use in aircraft engines. Upon use of the Multizone technology, a hard alpha defect approximately 1/4" long was found in the billet. The defect shown here was verified as hard alpha using metallography and chemical analysis. Without the Multizone inspection, the defective material would have moved forward in the production process, and if not detected by subsequent inspection processes, would have remained in the final engine. FAA funded technology successfully detected a hard alpha defect that was missed with conventional technology prior to its introduction into the US fleet—a true success story.



INSERVICE EDDY CURRENT INSPECTION OF JET ENGINES

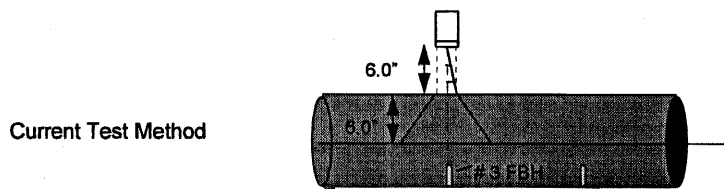
Aircraft engines are complicated engineered systems that are designed to operate at high stresses and high temperatures. The stresses and temperatures of operation can lead to inservice conditions that require monitoring or detection. One of the technologies used to detect cracking in inservice components is eddy current which utilizes electromagnetic waves to interrogate the region of interest. Cracks in the component of interest will result in a change to the electromagnetic field generated by the eddy current probe much like metal objects will signal an alarm in airport security systems. Eddy current technology presently in use by the aircarrier industry involves hand held probes designed for a particular application. The ETC has developed new tools to improve the sensitivity of eddy current inspection which are applicable across engine makes and models. Generic tools which can be used to inspect both Pratt & Whitney and General Electric engines are being designed for use in performing eddy current inspection at airline maintenance shops, a more cost-effective approach for the aircarriers.

Current approaches involve inspection of titanium material at the billet, forging, finished component, and aircraft engine phases. The Engine Titanium Consortium is developing tools to improve the sensitivity and/or the productivity of engine inspection. The program will address detection of material related defects in titanium as well as provide inservice tools for maintenance of the fleet.

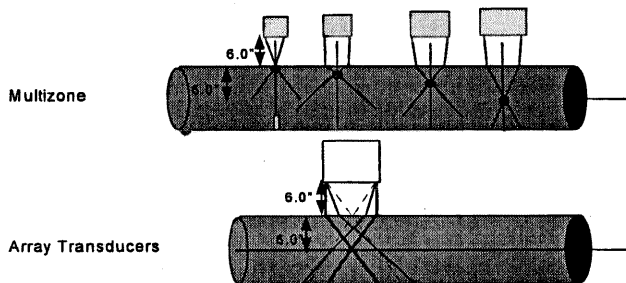
One of the defects of concern in titanium materials is the hard alpha defect, a brittle particle that can occur during the melting process. Catastrophic engine failures have been attributed to its existence, most notably the Sioux City crash of 1989. Tools being developed by the ETC include more sensitive inspection approaches for the detection of defects in titanium. Two recent successes include the detection of a hard alpha defect in titanium billet that was undetectable using existent technology and demonstration of new tools for inservice inspection of aircraft engines, as detailed below.

ULTRASONIC INSPECTION OF TITANIUM BILLET

During titanium production for engine applications, large hammer mills are used to reduce titanium ingot of approximately 24" diameter down to titanium billet that ranges from 6" to 14" in diameter. Ultrasonic inspection, a familiar technique to many because of its use in medical applications, is also used to determine the health of engineered components such as titanium billet. The billets are typically 10 to 20 feet in length when inspected. The conventional approach uses a single transducer to inspect the full diameter of the billet as shown in the diagram below:



The ETC is developing zoned approaches to inspection which interrogate specific zones of a component. Two approaches are under evaluation: multiple, discretely focused transducers and electronically controlled, phased array transducers. Both approaches divide the billet into multiple zones providing a more sensitive inspection which is uniform throughout the billet diameter. The Multizone system has the advantage of field implementation and demonstrated performance in billet production facilities. The phased array system may prove to be a more economical approach as it uses a single transducer, thereby reducing hardware costs. Array technology shows promise in forging inspection applications where access becomes more difficult as a result of geometrical features. A schematic of the two approaches is provided here:



IMPROVING SAFETY OF AIRCRAFT ENGINES: A CONSORTIUM APPROACH

OVERVIEW

With over seven million departures per year, air transportation has become not a luxury, but a standard mode of transportation for the United States. A critical aspect of modern air transport is the jet engine, a complex engineered component that has enabled the rapid travel to which we have all become accustomed. One of the enabling technologies for safe air travel is nondestructive evaluation or NDE which includes various inspection techniques used to assess the health or integrity of a structure, component, or material. The Engine Titanium Consortium (ETC) was established in 1993 to respond to recommendations made by the Federal Aviation Administration (FAA) Titanium Rotating Components Review Team (TRCRT) for improvements in inspection of engine titanium. Several accomplishments funded by the Aviation Grants Program under FAA Grant number 93-G-029 are detailed in this document.

The objective of the Engine Titanium Consortium is *to provide the FAA and the manufacturers with reliable and cost-effective new methods and/or improvements in mature methods for detecting cracks, inclusions, and imperfections in titanium.* The consortium consists of a team of researchers from academia and industry—namely, Iowa State University, AlliedSignal Propulsion Engines, General Electric Aircraft Engines, and Pratt & Whitney Engines—who worked together to develop program priorities, organize a program plan, conduct the research, and implement the solutions. The true advantage of the consortium approach is that it brings together the research talents of academia and the engineering talents of industry to tackle a technology-base problem. In bringing industrial competitors together, the consortium ensures that the research results, which have safety implications and result from FAA funds, are shared and become part of the public domain.

The ETC has at its core the development of improved inspection techniques for application throughout the lifecycle of engine rotating components fabricated from titanium. Titanium is material widely used in production of jet engines because of its strength to weight performance. To ensure its safe operation, titanium material is inspected at various stages in its lifecycle, as shown below. Although much of this sequence is common to other aircraft engine materials, the problem of inspecting titanium is particularly critical because of some unique microstructural issues.

